

Argonne National Laboratory

DESIGN AND PERFORMANCE CHARACTERISTICS OF EBR-II CONTROL ROD DRIVE MECHANISMS

by

E. Hutter and G. Giorgis

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OF EBR-II CONTROL ROD DRIVE MECHANISMS

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E. Hutter and G. Giorgis

Reactor Engineering Division

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I. INTRODUCTION

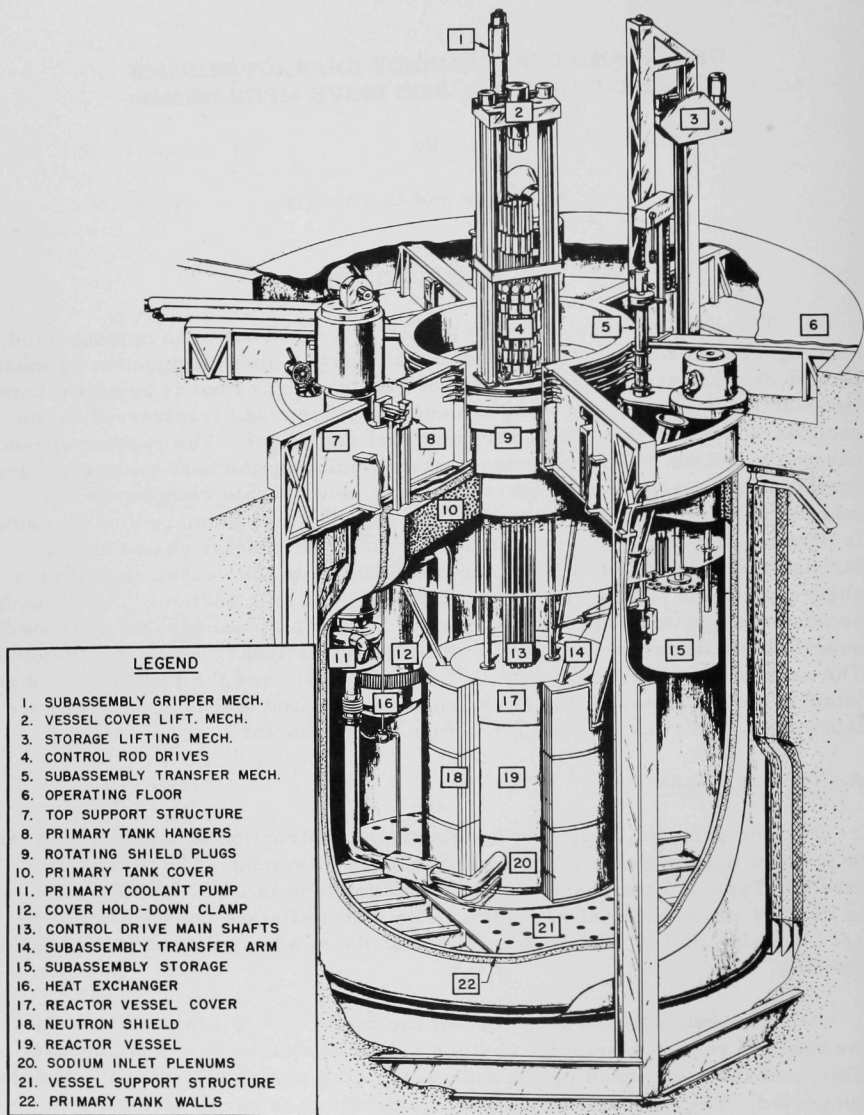
The Experimental Breeder Reactor-II (EBR-II) is an unmoderated, heterogeneous, sodium-cooled reactor and power plant designed to produce 20 MW of electricity from 62.5 MW of reactor heat. Heat is removed from the reactor by the primary sodium coolant system and transferred to the secondary system in a shell-and-tube heat exchanger. The reactor vessel assembly and the entire primary system (including the heat exchanger) are contained in a large vessel (primary tank), and operate completely submerged in the bulk sodium coolant (see Fig. 1). The primary sodium coolant is pumped directly from the bulk sodium into the reactor vessel and up through the core. The effluent coolant flows from the vessel, through the shell side of the heat exchanger, and back to the bulk sodium. The secondary sodium system (tube side) transfers the heat to a steam generator in which superheated steam is produced to drive a conventional turbine-generator. The reactor may be fueled with U^{235} or plutonium, and the plant includes an integral Fuel Cycle Facility in which the irradiated fuel is processed, re-fabricated, and reassembled for return to the reactor.

A. Primary Tank

The primary tank is of double-wall construction (a tank within a tank) to provide maximum reliability of sodium containment. The tank is fabricated of Type 304 stainless steel. The inner tank is 26 ft, and the outer tank is 26 ft 11 in. in internal diameter. The side walls are constructed of 1/2-in.-thick plates, whereas 1-in.-thick plates are employed for the tank bottoms.

The bottom-plate structure of the inner tank is designed to support the reactor vessel assembly, neutron shield, and the entire sodium load. This load is transferred by the tank wall to the top cover where the tank is supported. The outer tank structure is designed to carry only the sodium load in the event of a leak developing in the inner tank.

The bottom of each tank is stiffened with beams. A similar structure is used for the primary tank cover, which is 39 in. deep. (This depth is used for shielding material and thermal insulation.)



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Fig. 1. Reactor Assembly in Primary Tank

The space between the two tanks, and the region between the primary tank cover and the bulk sodium, is filled with inert gas (argon). The outside of the tank is insulated to reduce heat losses from the primary system.

The primary tank and its contents, and those components which are connected to the primary tank top cover, are supported by six hangers (welded to the top cover beams) which, in turn, transfer these loads to the top structure beams. Each hanger is supported by a roller so that differential radial expansion between the top structure and the primary tank cover (due to large differences in operating temperatures) will not impose any additional stresses in the system.

The primary tank design and the method of support are arranged to provide radial expansion about the vertical centerline of the system. The most critical units - the reactor, and the rotating plugs which index the control drives and fuel-unloading mechanism - are centered on the physical centerline of the system. Differential vertical expansion is reduced by using identical material for all equipment in the system, and maintaining it at the same temperature.

B. Reactor Vessel Assembly

The reactor vessel assembly (see Fig. 2) consists of the reactor vessel, the grid-plenum assembly, and the vessel cover. The assembly is surrounded by the neutron shield and is submerged beneath approximately 10 ft of sodium.

The reactor vessel is a cylindrical tank with flanged ends. The vessel wall is "insulated" from the bulk sodium by a second steel shell which is vented and, therefore, contains static sodium. This shell-and-static-sodium combination provides sufficient thermal insulation with acceptable thermal stresses in the vessel wall.

The grid-plenum assembly is a combination core-support grid structure which supports and locates the subassemblies, and incorporates the coolant inlet plenums. The grid structure is designed to accommodate 637 hexagonal subassemblies spaced on a triangular pitch of 2.320 in. The nominal core loading consists of 47 enriched uranium core subassemblies, 6 enriched uranium inner blanket-type subassemblies, 2 safety subassemblies, 12 control subassemblies, 60 natural uranium inner blanket subassemblies, and 510 natural uranium outer blanket subassemblies. Each subassembly contains a number of fuel elements and blanket elements of size and shape appropriate to the particular subassembly.

A single subassembly size is employed, resulting in a close-packed reactor geometry (see Fig. 3). Each hexagonal subassembly tube measures 2.290 in. across external flats, with a 0.040-in. wall thickness. There is a

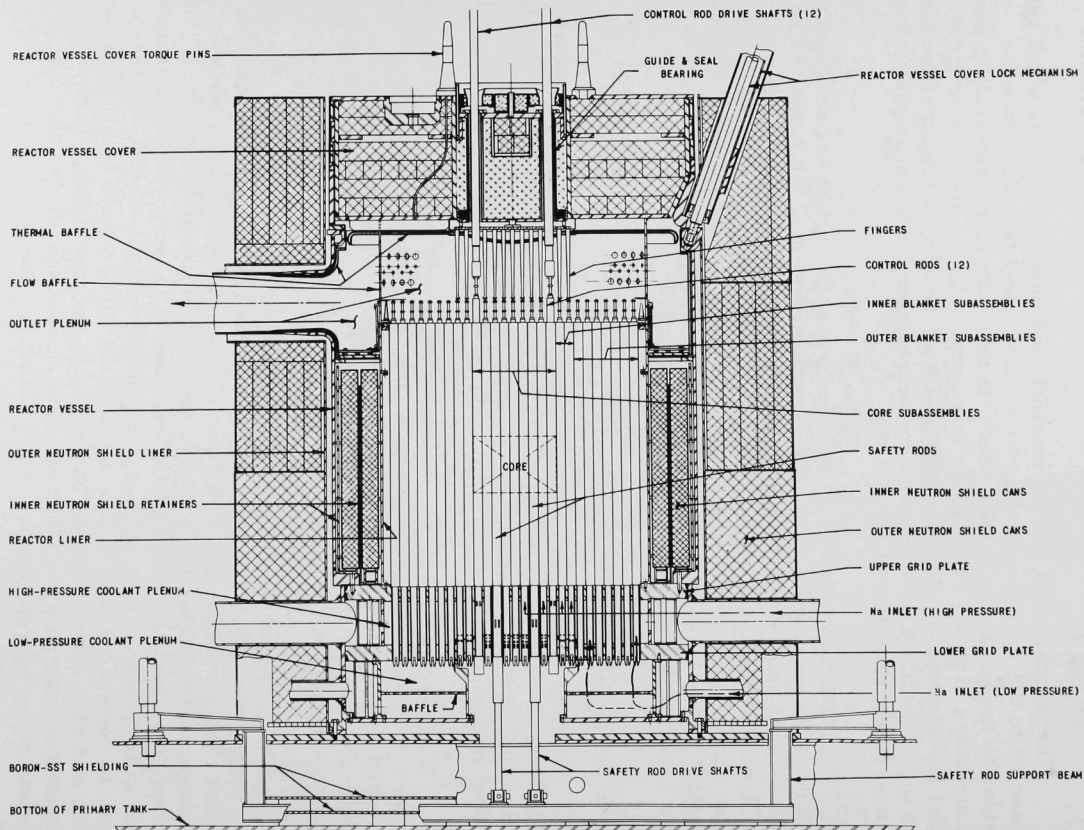


Fig. 2. Reactor Vessel Assembly

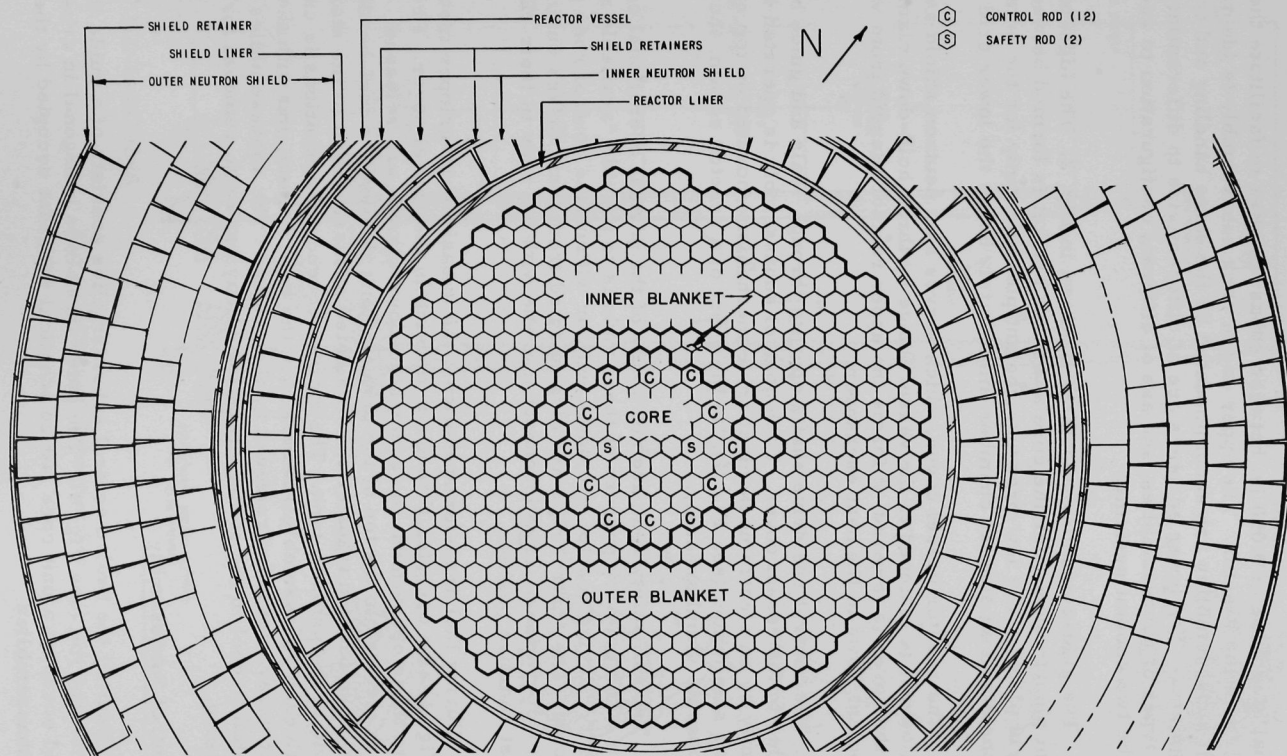


Fig. 3. Plan View of Reactor Lattice and Vessel Assembly

nominal clearance of 0.030 in. between subassemblies to facilitate their removal from the reactor. The upper end of each subassembly is identical, and all subassemblies are accommodated by the same handling and transfer mechanisms. The lower adapters are of different size to differentiate the three types of subassemblies, and are of different configuration to accommodate the two coolant systems.

The grid-plenum arrangement is shown in Fig. 2. The high-pressure coolant plenum supply for the core and inner blanket is formed between the two grid plates. The low-pressure coolant plenum supply for the outer blanket consists of an annular chamber immediately below the lower grid plate.

The reactor vessel cover, which serves as a neutron shield as well as a closure, is clamped to the vessel flange by three hold-down clamps. When the cover is lowered, it forms the upper reactor plenum from which the coolant flows to the heat exchanger.

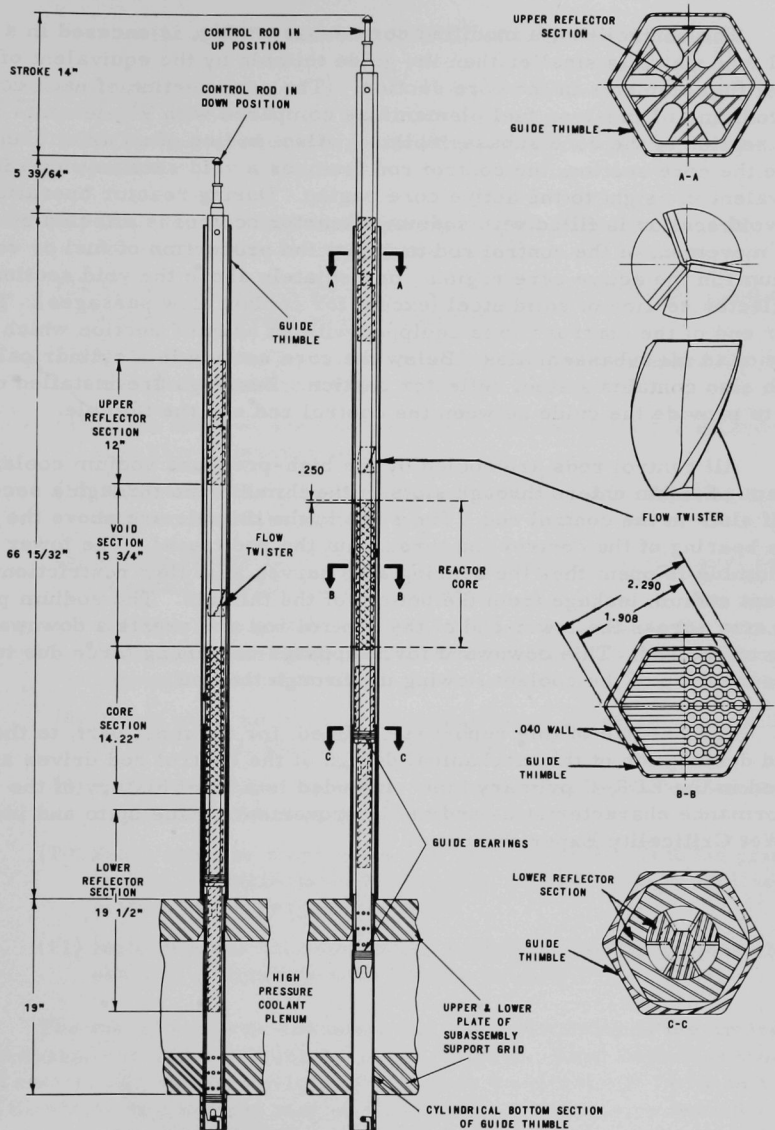
The control rod drive shafts operate through seals and guide bearings installed in the vessel cover. Each control subassembly is operated independently by an electromechanical drive mechanism mounted on top of the rotating shield plug (see Fig. 1). In the event of a reactor scram, the twelve rods operate simultaneously.

The two safety rods are not a part of the normal operational control system. The primary purpose of these rods is to provide "available negative reactivity" during reactor shutdown, with or without the control rods disconnected. The control rods are disconnected from their drives during fuel-transfer operations. The disconnect is made with the rods in their "DOWN" or least reactive position.

During fuel-transfer operations, the subassembly-gripper mechanism (see Fig. 1) also operates through an opening in the vessel cover. Preparatory to these operations, the cover hold-down clamps are released. The cover is elevated to the top of the primary tank to allow the fuel-handling system to unload and transfer the irradiated subassemblies to the storage rack within the primary tank. The entire sequence of operations is carried out with each subassembly submerged in the bulk sodium, and with the fission product decay heat being removed by the sodium. The subassemblies are permitted to cool in the storage rack for 15 days prior to removal for processing.

C. Control Subassembly

Each of the twelve control subassemblies consists of a guide thimble and a control rod (see Fig. 4). The guide thimble is hexagonal in cross section and occupies a unit core lattice identical with that occupied by the various subassemblies.



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Fig. 4. Control Subassembly

The control rod, a modified core subassembly, is encased in a hexagonal tube which is smaller than the guide thimble by the equivalent of one row of fuel elements in the core section. (The core section of each control rod contains 61 pin-type fuel elements as compared with 91 elements in the core section of the core subassemblies.) Also, in lieu of an axial blanket above the core section, the control rod features a void section which is equivalent in height to the active core region. During reactor operation, this void section is filled with sodium. Reactor control is effected by vertical movement of the control rod to adjust the proportion of fuel or void (sodium) in the active core region. Immediately above the void section is a reflector section of solid steel (except for coolant flow passages). The upper end of the control rod is equipped with an adapter section which is common to all subassemblies. Below the core section is a cylindrical tube which also contains a steel reflector section. Bearings are installed on this tube to provide the guide between the control rod and the thimble.

All control rods are cooled by the high-pressure sodium coolant system. Sodium enters through slots in the thimble and through a second set of slots in the control rod. The slots in the thimble are above the lower guide bearing of the control rod throughout the rod travel. The lower end of the thimble is open; thus the bearing also serves as a flow restriction to prevent sodium leakage from the bottom of the thimble. The sodium pressure acts across the lower end of the control rod and exerts a downward force on the rod. This downward force opposes the lifting force due to the pressure drop of the coolant flowing up through the rod.

The balance of this report is confined, for the most part, to the detailed description of the mechanical design of the control rod drives as installed in the EBR-II primary tank. Included is a brief history of the performance characteristics and the improvements made up to and including the Wet Criticality Experiments.

II. CONTROL ROD DRIVE MECHANISMS

A. Design Criteria

The following criteria were established for the design of the control rod drive system:

- (1) One identical and interchangeable drive mechanism is to be used for each of the twelve control rods.
- (2) All drive mechanisms are to be mounted within the limited area above the closely spaced control rods.
- (3) Each rod is to be driven vertically at uniform speed for a total travel distance of 14 in.
- (4) Drive and rod shall be capable of scram from any raised position at accelerated speeds of 1-2 g.
- (5) There shall be a small elapsed time between initiation and response of scram stroke.
- (6) Scram stroke is to be decelerated over $4\frac{1}{8}$ in. of travel before reaching "FULL DOWN" position.
- (7) Control rods and drives shall include provisions for remote-controlled disengagement to facilitate fuel-transfer operations within the primary tank.
- (8) There shall be positive disengagement of drives with the rods in the "FULL DOWN" position only.
- (9) Each drive shall include a "sensing" feature to confirm engagement and/or disengagement of the control rod.
- (10) Seals shall be employed at all shaft penetrations in the primary tank to maintain gastight integrity without restricting linear motion of the respective shafts.
- (11) Materials for all components extending into the primary tank shall be compatible with sodium at 900°F.

The major features and operating characteristics of the control rod drive design evolved are summarized in Table 1. Each control mechanism is an electrically driven device which moves a control rod 14 in. in a vertical direction at a normal rate of 4.76 in./min. Each drive features a pneumatic piston coupled with a hydraulic shock absorber which effect acceleration and deceleration of the fast, downward scram stroke.

Table 1

SUMMARY OF CONTROL ROD DRIVE DESIGN
AND OPERATING CHARACTERISTICS

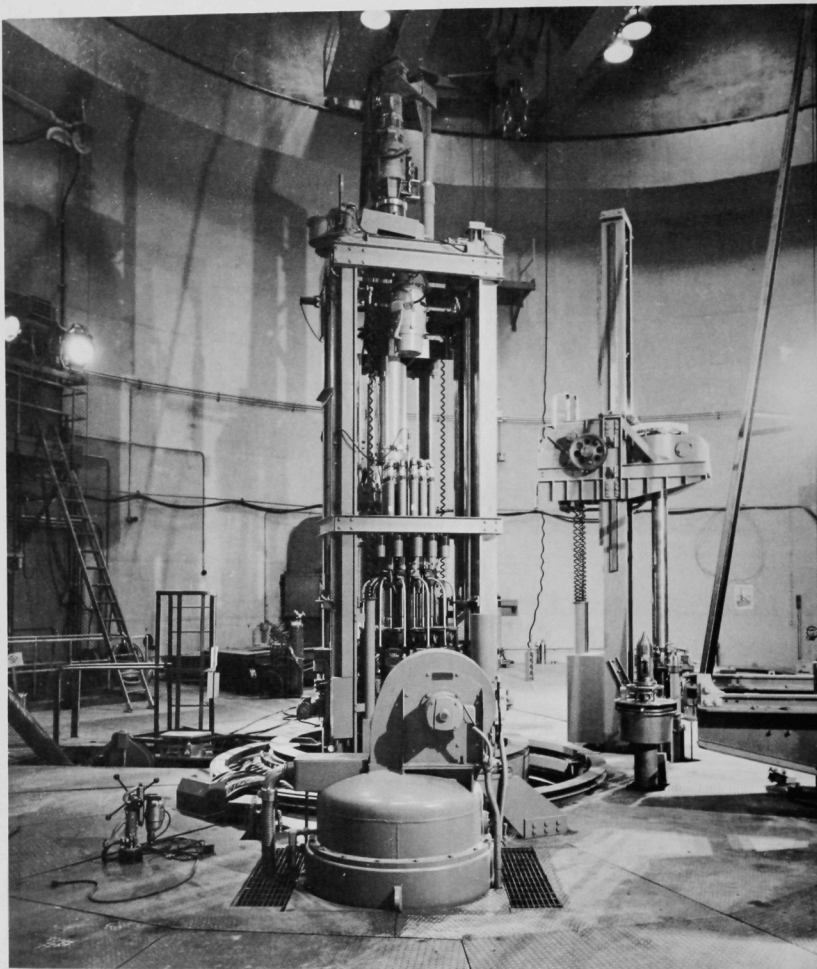
Number of control rods and drives	12
Radial distance from vertical core centerline (avg)	8.66 in. (22.0 cm)
Calc reactivity worth of each rod	0.004 $\Delta k/k$
Nature of drive	Electromechanical with pneumatic scram assist
Distance of vertical travel	14 in. (35.56 cm)
Vertical control speed	4.76 in. (12.09 cm)/min
Scram time for the initial 11 in. of 14-in. travel	~0.230 sec
Scram speed (max)	8.5 ft (259 cm)/sec
Scram delatch time	0.014-0.020 sec
Scram acceleration	1-2 g (actual operation = 1.5 g max)
Pressure in pneumatic scram assist	0-50 psig (actual operation = 30-33 psig)

The twelve control rod drives are mounted on a common lifting platform atop the rotating shield plugs above the primary tank. The platform can be (1) raised from its normal operating position to prevent interference between the lower ends of the drive shafts and the adapters of the fuel sub-assemblies during fuel transfer, and (2) lowered to permit gripping of the control rods. Figure 5 shows the manner in which each drive is mounted to a central support column on the lifting platform. Figure 6 shows the control rod drive complex and other fuel-handling mechanisms, which are also mounted on top of the rotating shield plugs. Figure 7 is a plan view of these mechanisms and related equipment installed on the operating floor.



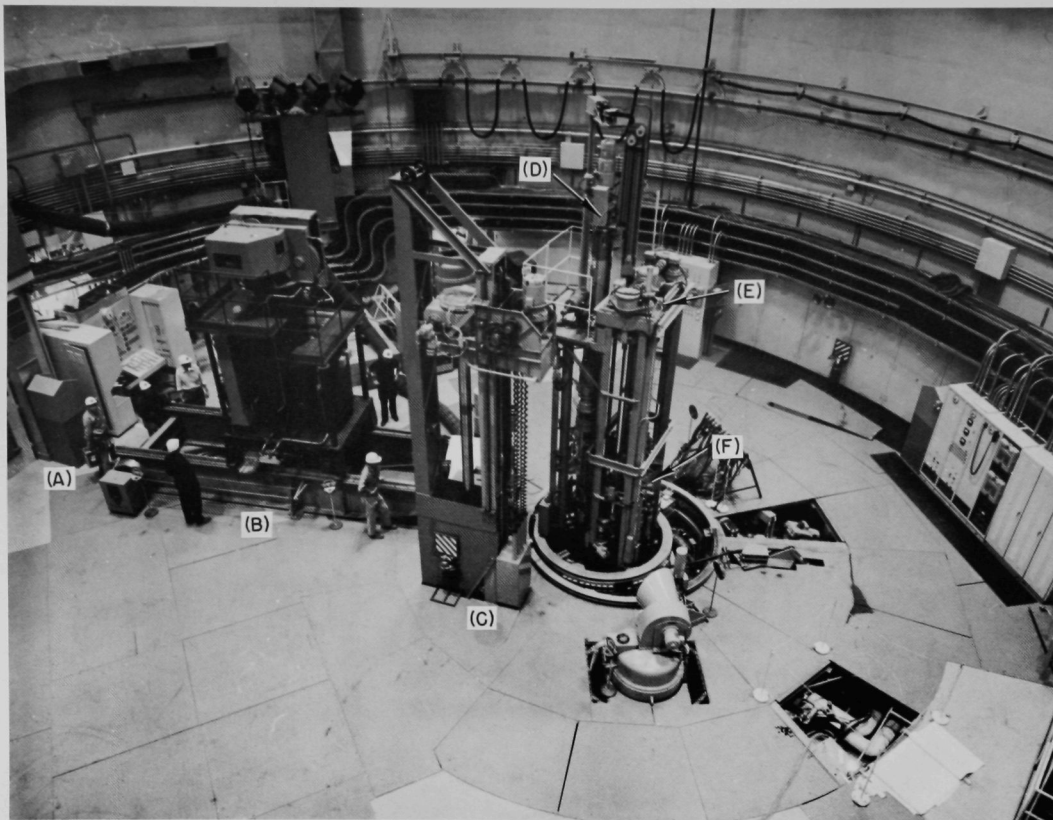
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Fig. 5. (A) Single Drive and (B) Complete Assembly of Twelve Control Rod Drives Mounted on Lifting Platform



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Fig. 6. Control Rod Drives and Fuel-handling Mechanisms
Installed on Rotating Shield Plugs

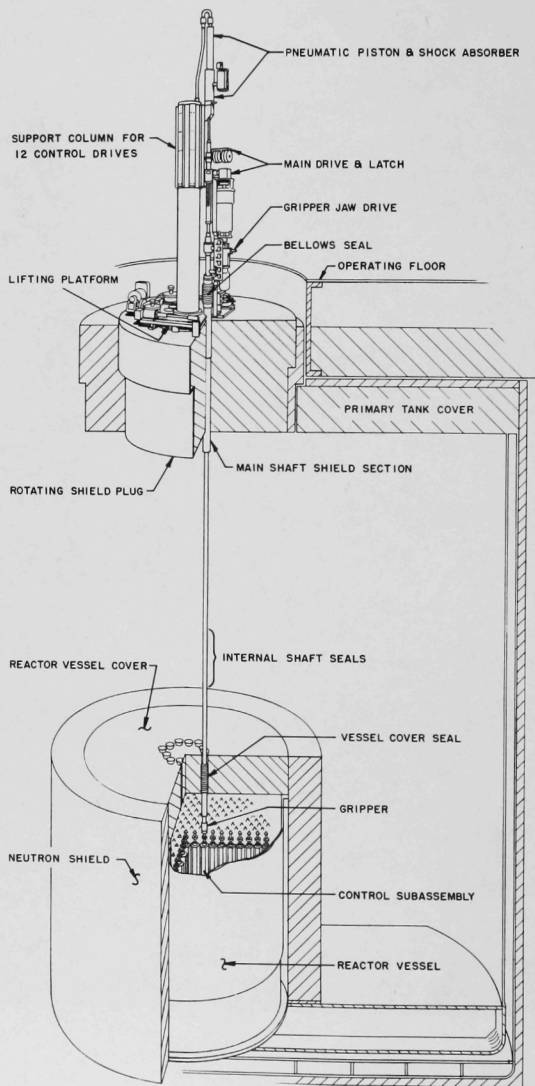


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Fig. 7. Arrangement of Control Rod Drive Complex, Fuel-handling Mechanisms, and Related Equipment on Reactor Operating Floor:
 (A) Fuel-handling Console; (B) Fuel-unloading Machine; (C) Subassembly Storage Rack Mechanism; (D) Subassembly Gripper
 Mechanism; (E) Vessel Cover Lifting Mechanism; (F) Control Rod Drive Mechanisms

B. Mechanical Design

The following descriptions of the mechanical components apply to each of the twelve control rod drives, starting with the gripper at the lower end of the simplified pictorial in Fig. 8.



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Fig. 8. Simplified Pictorial of Components of Control Rod Drive

1. Gripper

The function of the gripper is to grip or to release the control rod. As shown in Fig. 9, the gripper consists of two jaws supported by a common shaft. The jaws are opened or closed over the cone-shaped end of the control rod adapter by sliding two parallel bars against their back sides. The parallel bars are fastened to the inside of a cylinder surrounding the upper part of the jaws and which can be moved vertically $1\frac{1}{2}$ in. with respect to the jaws. The teeth of the jaws which actually support the adapter head protrude through a guide funnel. This design feature allows the jaw teeth to recede past the guide funnel upon opening and thus eliminates any possibility for the adapter head to hang up on a jaw tooth due to slight misalignment of the control rod and gripper.

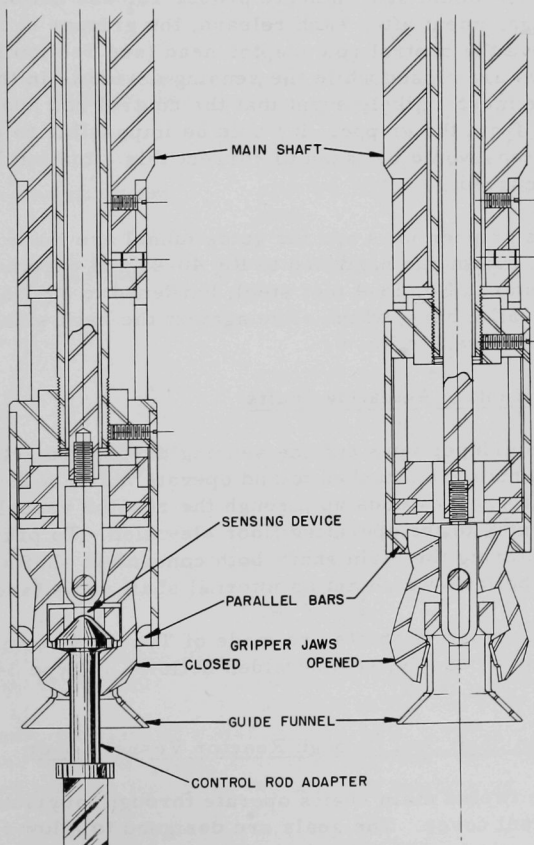


Fig. 9. Control Rod Gripper

To give added assurance of having gripped or released a sub-assembly, the gripper includes a sensing device. It consists of a plunger which straddles the gripper jaw shaft and is made to move vertically $\frac{3}{4}$ in. by the control rod adapter. If necessary, it can be used to forcibly eject the adapter. Movement of the sensing device transmits a positive indication to the fuel-handling console as to whether a control rod adapter has entered or left the space between the open gripper jaws.

However, in the interests of reactor safety, it is imperative to know that the control rod adapter actually has been separated from the gripper jaws after release of the control rod. For example, it must be established that the control rod adapter has not stuck to the underside of the sensing device or to the lower part of the guide funnel; in either event, the sensing device would still indicate proper release action. To insure complete disengagement after each release, the gripper is lifted to an elevation well above the control rod adapter head (see Section II-B-13). Then the gripper jaws are closed while the sensing device is in the "empty" position. In the most unlikely event that the control rod adapter should not have separated from the gripper, it would be impossible to completely close the jaws, and steps would be taken to correct this situation before any damage was incurred.

The gripper jaws and the guide funnel are made of Type 420 stainless steel, drawn and hardened to R_C 40-45 and chrome plated. The jaw shaft material is No. 18-4 tool steel, hardened to R_C 55 and chrome plated. The parallel bars, which slide against the back sides of the gripper jaws, are made of Stellite No. 6.

2. Concentric Actuating Shafts

The gripper jaws and the sensing device are actuated by concentric shafts which are attached to and operate inside a 26-ft-long main shaft. The main shaft extends up through the reactor vessel cover and the rotating shield plug to the operating floor elevation. To prevent primary sodium from entering the main shaft, both concentric shafts are welded to stainless steel bellows which act as internal shaft seals (see Fig. 10).

The actuating shafts are made of Type 304 stainless steel. The shaft seals feature two-ply, seam-welded bellows of Type 347 stainless steel sheet (0.010 in. thick).

3. Main Shaft Seal through Reactor Vessel Cover

The twelve main shafts operate through labyrinth-type seals in the reactor vessel cover. The seals are designed to allow free vertical movement of the shaft, with minimum outleakage of the primary sodium coolant.

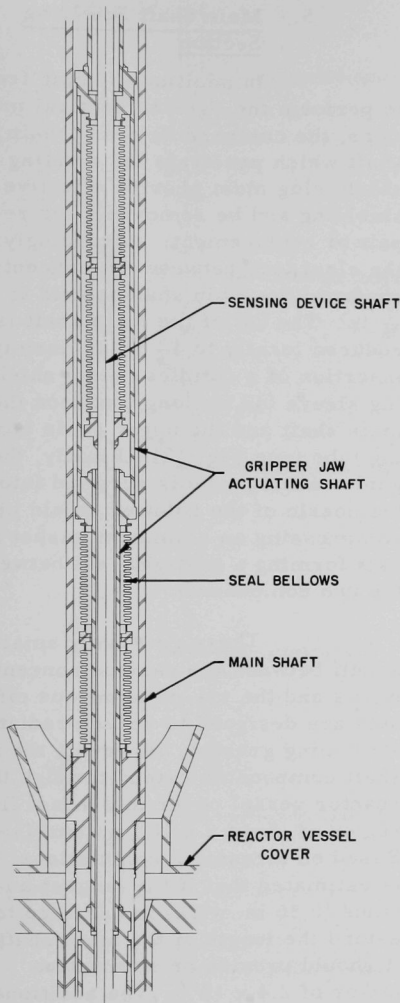


Fig. 10. Control Rod Drive Internal Shaft Seals

the primary tank, consists of a Stellite ring with a radial clearance of 0.022 in. around the main shaft. It is fastened to a guide bearing tube which can be removed through the top of the rotating shield plug.

Each seal (see Fig. 11) consists of a grooved cylinder mounted on the shaft at the proper elevation so that it can slide 14 in. within a companion sleeve installed in the vessel cover. The cylinder is 12 in. long, with an OD of 2.535/2.531 in., and is made of AMPCO No. 18-13 alloy (10.6% Al; 3.6% Fe; ~85.8% Cu). The OD is interrupted by 23 circumferential grooves, each 0.250 in. wide and 0.087 in. deep. The companion sleeve is $29\frac{1}{8}$ in. long, with an ID of 2.559/2.567 in., and is made of wrought Stellite No. 6B.

The calculated leak rate of each seal is 3.4 gpm of sodium. This rate is based on 100% sodium flow through 67 core subassemblies, and a 9.6-psi differential between the upper vessel plenum filled with 900°F sodium and the 700°F bulk sodium in the primary tank.

4. Main Shaft Bearings inside Primary Tank

The main shaft of each control rod drive extends about 15 ft from the top of the reactor vessel, through the bulk sodium, to the underside of the rotating shield plug. This portion of the shaft, which is $2\frac{1}{2}$ in. in diameter over most of its length, is guided at two elevations. The labyrinth seal in the vessel cover serves as the lower guide bearing, since it is only 21 in. above the gripper.

The second guide bearing, located about 8 ft above the vessel cover and just below the bulk sodium level in

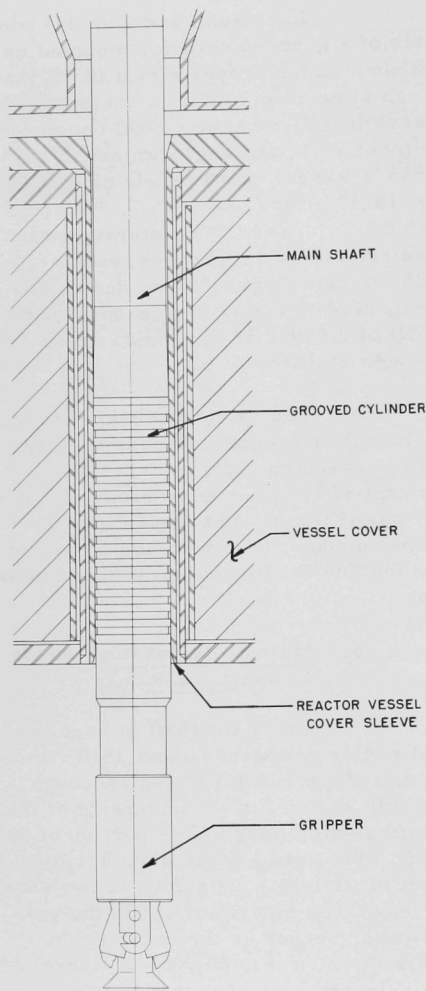


Fig. 11. Main Shaft Seal through Reactor Vessel Cover

shaft. Similar calculations indicate an emission rate of < 1 mR/hr at the same location due to streaming from gamma-ray flux of about 6×10^9 MeV/(cm²)(sec) emanating from the sodium in the primary tank.

An uncertainty exists concerning the neutron flux in the keV range. Along with the intermediate-energy neutrons, the associated capture

5. Main Shaft Shielding Section

In addition to being free to perform the various vertical motions, the components of the main shaft which penetrate the rotating shield plug must provide effective shielding and be removable for repair or replacement. Accordingly, the clearance between the concentric shafts in the main shaft is held to $\frac{1}{16}$ in. The OD of the main shaft is reduced locally to $1\frac{5}{8}$ in. to permit insertion of a stainless steel shielding sleeve (42 in. long) between the main shaft and the upper guide bearing tube (see Fig. 12). Finally, the guide bearing tube is screwed into the nozzle of the rotating shield plug, compressing an aluminum gasket and thus forming a gastight seal between the two components.

These relatively small annuli between the various concentric shafts and the use of numerous off-sets are designed to reduce radiation streaming greatly. However, the main shaft components extend through the reactor vessel cover into a fast flux region of about 5×10^{10} n/(cm²)(sec). Based on streaming calculations, it is estimated that if the largest annulus (0.56 in. wide) is assumed to extend the length of the main shaft, it should provide an attenuation factor of 2.4×10^{-4} . The additional shielding provided by the steel in the annulus should give an uncollided neutron flux of < 20 n/(cm²)(sec), or about 2 mR/hr, at the top of the main

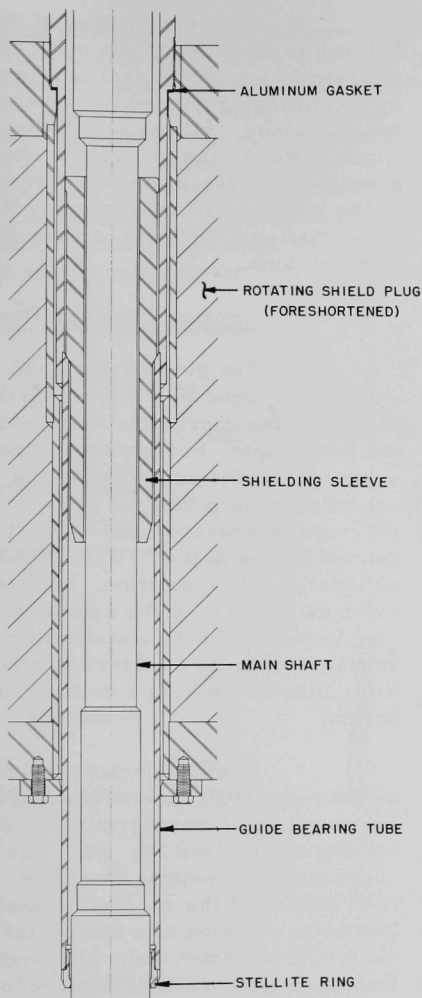


Fig. 12. Main Shaft Shielding Section in Rotating Shield Plug

gastight seal. Also positioned at the same elevation is a main shaft guide bearing, an AMPCO No. 18-13 alloy ring which provides a radial clearance of 0.011 in. around the main shaft. Sections of the ID of the ring are relieved to permit gas flow in and out of the bellows during control rod strokes and scrams.

gamma rays will contribute to the uncertainty of the radiation levels near the control rod drives. Thus the possibility exists that the total dose may be above tolerance, requiring some additional shielding on top of the rotating shield plug.

6. Main Shaft Seal above the Biological Shield

Above the biological shield, the annulus between the main shaft and the guide bearing tube in the rotating plug is terminated by a nesting-type bellows seal. The purpose of the seal is to prevent argon gas leakage from the primary tank without impairing vertical motion of the main shaft.

The bellows seal, shown in Fig. 13, is composed of 198 disks which are welded together at the inner and outer edges. Each disk is made of Type 347 stainless steel and measures $2\frac{9}{16}$ in. in ID, $4\frac{1}{2}$ in. in OD, and is 0.010 in. thick. During downward travel of the main shaft, the disk portion of the bellows is compressed from $19\frac{7}{8}$ in. to $5\frac{7}{8}$ in. During the control rod "pick-up" sequence, the bellows is compressed an additional $\frac{7}{8}$ in. to 5 in. by lowering the lifting platform (see Section II-B-13).

The lower fitting of the bellows is threaded onto the top end of the guide bearing tube, compressing an aluminum gasket to effect a

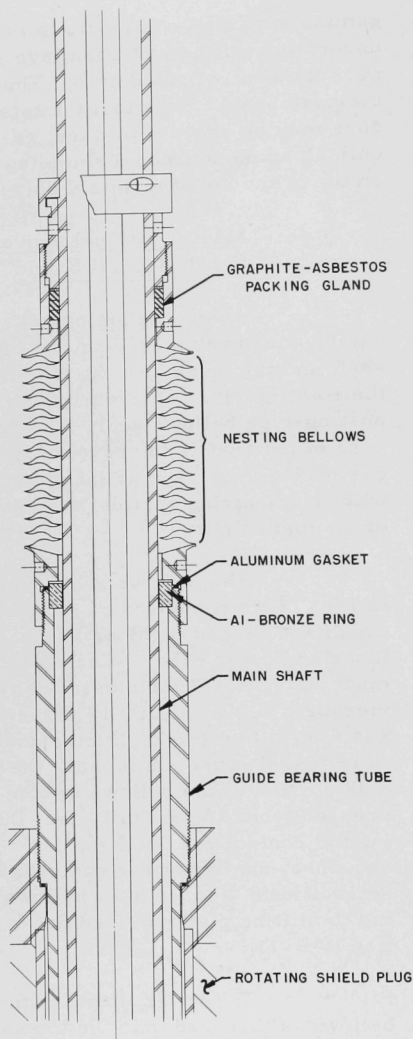


Fig. 13. Main Shaft Bellows Seal
above Rotating Shield Plug

forced against two stationary pins which engage the serrations and thus prevent shaft rotation.

The remaining components of the gripper-actuating device are mounted on the control rod drive frame which, in turn, is mounted on the

The upper fitting of the bellows is threaded to the main shaft, whereupon a gastight seal is effected by compressing a graphite-asbestos packing gland. All parts of the seal which fasten to the main shaft can be disengaged to facilitate replacement of the bellows without removing the main shaft and the gripper from the primary tank.

7. Gripper Actuating Device

The gripper jaws are opened or closed by a $1\frac{1}{2}$ -in. vertical motion of the concentric shaft inside the main shaft. For reasons of reactor safety, the actuating device is constructed such that the gripper jaws can be operated only when the control rod is in the "FULL DOWN" or least reactive position. Also, as much as possible of the actuating device is mounted onto a stationary support to reduce exposure to shock loads incurred during a control rod scram.

The components mounted on the main shaft include the gripper-jaw-actuating screw drive and a shaft-locking device (see Fig. 14). The screw drive translates the $1\frac{1}{2}$ -in. vertical motion of the concentric shaft into rotary motion of a horizontal shaft with a slotted end. The shaft-locking device prevents rotation of the concentric shaft and, therefore, gripper actuation during normal operation of the control rod. This is accomplished by use of a spring-loaded, serrated disk which is keyed to the horizontal slotted shaft. The disk is

lifting platform. These include a $\frac{1}{20}$ -hp, 60-cycle, 3-phase motor, a spring-loaded sliding shaft, and a solenoid-operated lever which is attached to a sleeve that encircles the sliding shaft. The motor is coupled through a spur gear and a 90-V, DC magnetic clutch to an angle drive. This drive rotates the sliding shaft, one end of which is machined to engage the slotted end of the horizontal shaft of the shaft-locking device. Both shafts are coupled by energizing the solenoid-operated lever which moves the sliding shaft to the "Drive Position." Simultaneously, the sleeve forces disengagement of the serrated disk in the shaft-locking device. Upon de-energizing the solenoid, the spring retracts the sliding shaft to the "Disconnect Position."

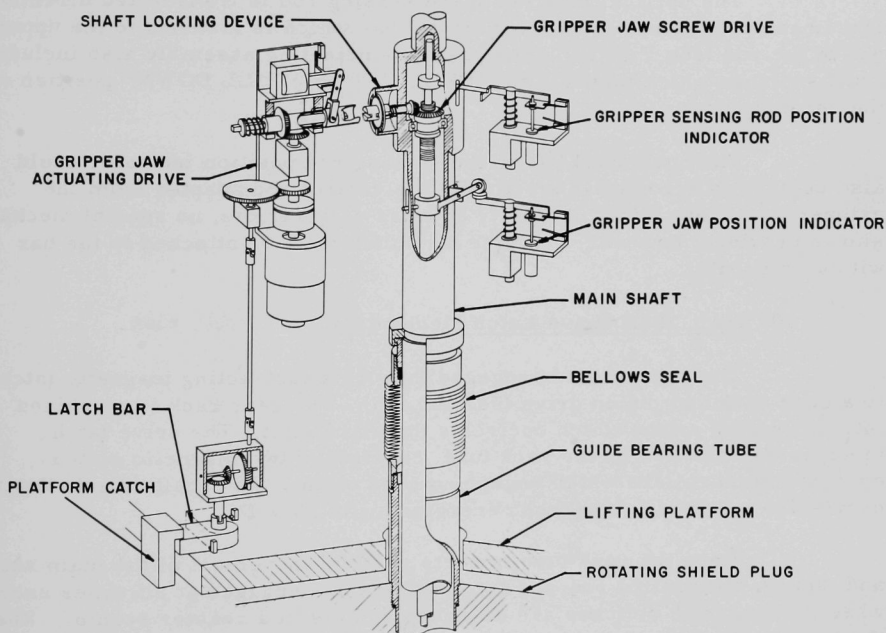


Fig. 14. Control Rod Gripper Jaw Drive and Lifting Platform Mechanical Interlock

The position of the vertical gripper-jaw-actuating shaft throughout its $1\frac{1}{2}$ -in. travel is derived from a linear potentiometer which is actuated by a lever arm attached to the shaft. Also included in the position-indicating assembly are limit switches which indicate the fully closed or open positions of the gripper jaws.

8. Mechanical Interlock with Lifting Platform

Two of the gripper-jaw drives on opposite sides of the control drive assembly also operate mechanical interlocks which restrict vertical

movement of the lifting platform. The rotating motion which actuates the gripper jaws is transmitted through a set of gears, driveshafts, and speed reducers to two latch bars which are mounted on the lifting platform (see Fig. 14). The latch bars are engaged by respective platform catches which are bolted to the rotating shield plug. Only when the gripper jaws of the control rod drives are open will the two latch bars be in a position which will not impede the raising of the lifting platform.

9. Sensing Rod Position Indicator

The vertical position of the sensing rod is transmitted directly to a linear potentiometer by a horizontal bar which is fastened to the upper end of the rod (see Fig. 14). The position-indicating assembly also includes limit switches which indicate the "FULL UP" or "FULL DOWN" position of the sensing rod.

The horizontal bar of the sensing rod position indicator could also be used to accomplish ejection of the control rod adapter from the gripper jaws. Since this necessity appears very remote, no special mechanism is provided; however, a simple hand tool could be attached to the bar without difficulty.

10. Main Shaft Drive Latch Mechanism

The main shaft is engaged through a fast-acting magnetic latch to a gear rack and pinion drive (see Fig. 15). The gear rack is machined into the wall of a tube which encircles the main shaft. The drive latch mechanism, mounted on the rack tube, consists of two magnetic clutch-operated latch rollers which engage notches on the main shaft. Each clutch exerts 480 in.-lb of torque when energized with 90 V DC.

Since the rack tube imparts vertical movement of the main shaft and, hence, the control rod, the latch rollers are engaged at all times except when the magnetic clutches are de-energized (as in a reactor scram). Then the latch rollers are forced outward, releasing the main shaft. The shaft is forced downward by gravity and by air pressure against the pneumatic piston (see Section II-B-12).

Laboratory tests have shown a release time of 0.008 sec, including the time elapsed between actuation of the scram button and beginning of shaft motion. Subsequent to installation in the reactor, the measured release time varied between 0.014 and 0.020 sec, depending upon the air pressure applied against the pneumatic piston.

After a scram, the latch mechanism is automatically lowered to the bottom position by the control drive. At this elevation, the two latch

rollers again engage the notches on the main shaft, the clutches are energized, and the control drive is ready to raise the rod at the proper signal.

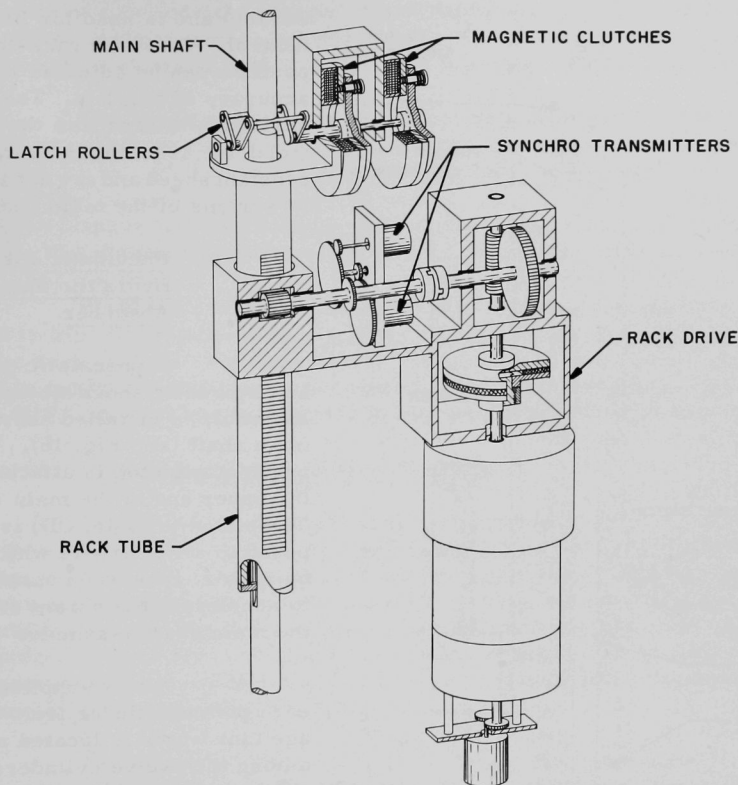


Fig. 15. Control Rod Drive Latch Mechanism

11. Control Rod Drive and Position Indicator

The rack tube is driven vertically over 14 in. at 4.76 in./min by the rack pinion. The torque is supplied through a worm gear, torque limiter, and speed reducer by an instantly reversible, $\frac{1}{6}$ -hp, polyphase motor equipped with a motor brake (see Fig. 15). The motor and gear assembly drive the rack tube (and main shaft) in the upward direction only, and act as a brake on the downward stroke.

The position of the rack tube is determined by two synchro-transmitters which are driven by a gear mounted directly on the rack

pinion shaft. One transmitter rotates 126° over the full 14-in. stroke and provides a coarse indication. The other transmitter completes 12.6 revolutions (36 times as much accuracy) and is used for fine control. Thus, the rack-tube position can be adjusted with an accuracy of ± 0.01 in. The synchrotransmitters and the control drive assembly operate at a constant speed and are not affected by scrams of the main shaft.

12. Pneumatic Piston and Hydraulic Shock Absorber

A pneumatic piston and hydraulic shock-absorber assembly is installed above each main shaft (see Fig. 16). The pneumatic piston is attached to the upper end of the main shaft. The piston (of 3-in. OD) is exposed to air pressure which can be regulated between 0 and 50 psig to accelerate the scram stroke of the main shaft assembly.

Air is supplied to each piston cylinder from a storage tank which is located centrally among the twelve cylinders. The storage tank is equipped with a pressure gauge, an automatic high- and low-pressure alarm, and a high-pressure relief valve. In addition, each of the interconnecting hoses features a flow-check device which closes automatically when the hose is disconnected.

A metal spacer ring is fastened to the wall of the cylinder above the piston. The ring serves as a positive mechanical stop for the upstroke of the piston

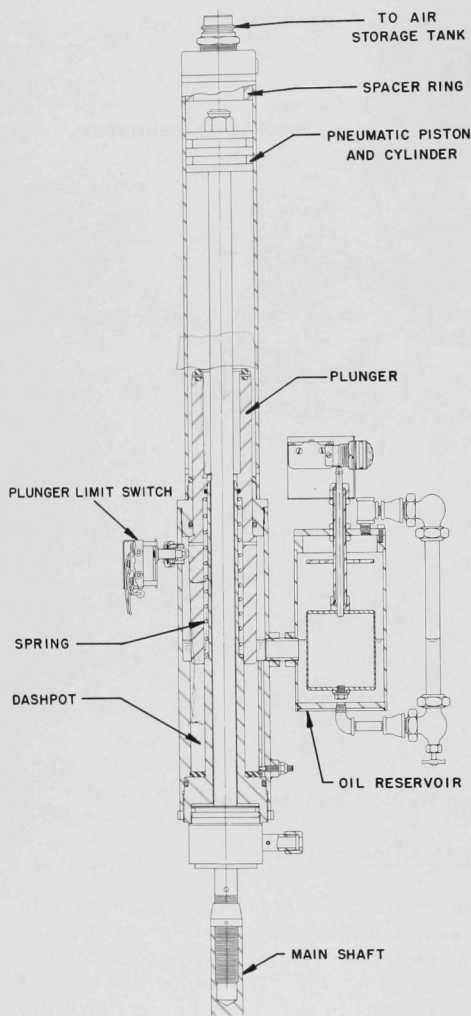


Fig. 16. Pneumatic Piston and Hydraulic Shock Absorber Assembly

and, hence, prevents overtravel of the control rod in the event the rod limit switches should fail.

The hydraulic shock absorber is supported by a bracket on the central support column and fastened to the lower end of the piston housing. It consists of a cylindrical plunger which extends up into the piston cylinder, an oil-filled dashpot, and an oil reservoir. The oil reservoir is equipped with a sight level gauge, and a float which energizes a low-level alarm.

The shock absorber operates as follows: In the event of a control rod scram from the "FULL UP" position, the piston is accelerated downward $9\frac{7}{8}$ in. At this point, the piston strikes the plunger and is decelerated over the remaining $4\frac{1}{8}$ in. of its stroke. The piston forces the lower end of the plunger into the dashpot, displacing the oil and thus absorbing the energy. The displaced oil flows into the oil reservoir.

When the control rod (and piston) is raised, the plunger is returned to the "UP" position by a spring, and the oil flows by gravity back into the dashpot. An electrical switch, actuated by a boss on the plunger, provides positive indication in the control room that the plunger has returned to the "UP" position and is ready to decelerate another rod scram.

13. Control Rod Drive Lifting Platform

The twelve control rod drives are mounted on a common platform (see Fig. 5) which can be raised 3 in. and lowered $\frac{7}{8}$ in. from its normal operating elevation. The platform is raised to ensure (1) that the control rod grippers are disengaged from the adapters of their respective control subassemblies; and (2) that the grippers are clear of the adapters of other subassemblies in the core. The latter is necessary since the control rod drives are supported by the shield plug which is rotated to position the unloading mechanism over various spent fuel subassemblies.

The platform is lowered to re-engage the control rod drives to the control subassemblies. The lower adapter of each subassembly has a built-in spring damper (see Fig. 17) which is partially compressed when the control rod rests on its support and orientation bar in the core grid structure. These springs are compressed further when the platform (and drives) is lowered to make certain that the upper adapter of each control rod is fully inserted into its respective drive gripper.

Vertical movement of the platform is effected by four screw-jacks which are coupled by appropriate drive shafts and a mechanical slip clutch to a $\frac{1}{2}$ -hp motor (see Fig. 18). The "UP" and "DOWN" stops are controlled by electrical switches. These switches are backed up by the mechanical interlocks described in Section II-B-8 and shown in Fig. 14.

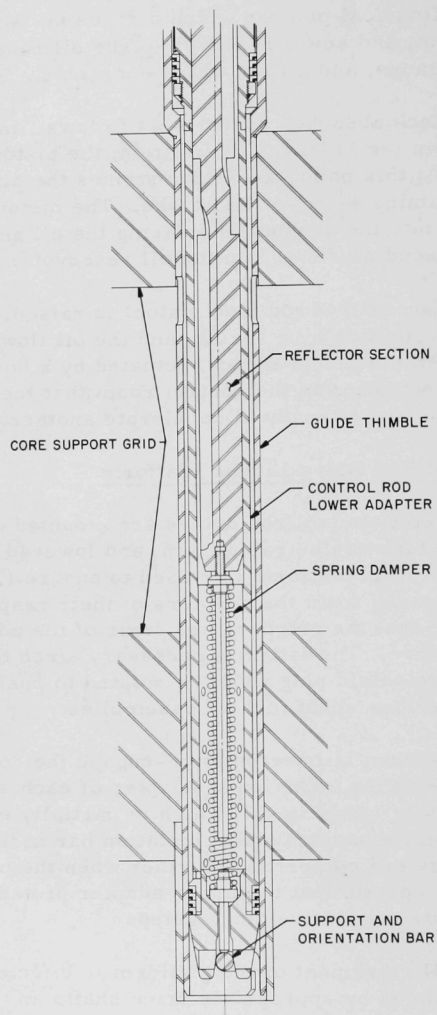


Fig. 17. Spring Damper in Lower Adapter of Control Rod

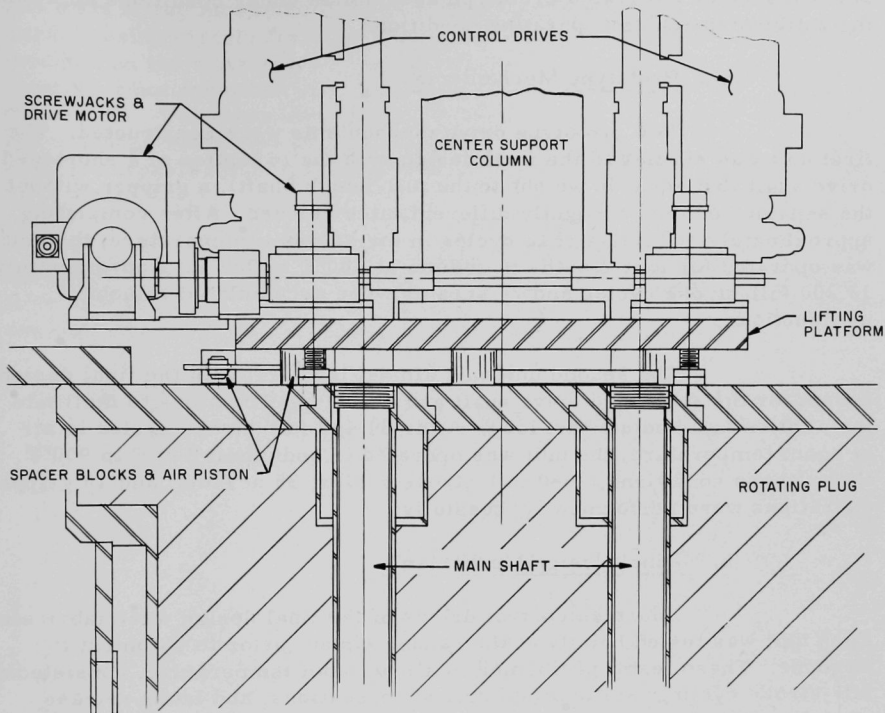


Fig. 18. Lifting Platform-Spacer Block Drive Assembly

When at the "operating level," the platform rests on six steel spacer blocks. These blocks are connected to a pneumatic piston which moves them laterally into recesses in the platform, when lowering of the platform is required. The platform drive is designed such that the motor continues to operate for several seconds after reaching the operating level to assure proper seating of the platform on the spacer blocks.

C. Performance Characteristics

1. Pre-installation Tests

Pre-installation tests ranged from feasibility studies of critical components during the early design stages to comprehensive tests to evaluate

performance of integrated prototype assemblies under conditions approximating anticipated reactor operating conditions.

a. Prototype Mechanisms

Two prototype drive mechanisms were constructed. The first unit was similar to the final design with the exception of a shortened drive shaft (but equal in weight to the full-length shaft), a gripper without the sensing rod, and a slightly different latch release. After completing approximately 300 full-stroke cycles in air at room temperature, the unit was operated for four months in sodium at 300°F to 900°F. Approximately 13,200 full-stroke cycles and 24 scrams were accumulated without malfunction.

The second unit was almost identical with the final design except for the shortened drive shaft and minor modifications to facilitate installation in a sodium test loop. After 31,440 full-stroke cycles in air at room temperature, the unit was operated in sodium at 300°F to 900°F. Under these conditions, 1680 full-stroke cycles, 35 scrams, and 15 gripper operations were performed successfully.

b. Final-design Mechanisms

Fourteen control drives of the final design were fabricated. Each unit was tested briefly at the vendor's plant prior to shipment to Argonne. These tests, performed in air at room temperature, consisted of full-stroke cycling, scrambling, gripper operations, and latch-release measurements.

At Argonne, one of the drives was subjected to rigorous tests for a period of about six months. The history of these tests is summarized below.

<u>Environment</u>	<u>Temp, °F</u>	<u>Full-stroke Cycles</u>	<u>Gripper Operations</u>	<u>Scrams</u>
Air	Room	900	20	120
Air	800	700	6	5
Sodium	750	1100	18	80

2. Post-installation Tests

a. Preliminary Scram Tests

After installation, and before the primary tank was filled with sodium, the control rod drives were tested to obtain scram data.

Delatch times (time elapsed between de-energization of latch-roller clutches and start of rod movement) were obtained through use of a two-brush recorder, using signals from the clutch circuit and a break-away contact mounted on the drive shaft. The equipment used to measure rod displacement vs. time consisted of a cable with one end attached to the control drive shaft. The other end was connected to a rotatable, spring-loaded drum around which was affixed pressure-sensitive graph paper. A solenoid plunger, capable of oscillating at 60 cps, was positioned to mark the paper as it rotated.

Preparatory to each scram, the piston cylinder was pressurized to 35 psig. The results (see Fig. 19) showed an average delatch time of 0.020 sec. The average total rod drop time was 0.424 sec, and the average acceleration over the first 9 in. of rod travel was 50.1 ft/sec^2 .

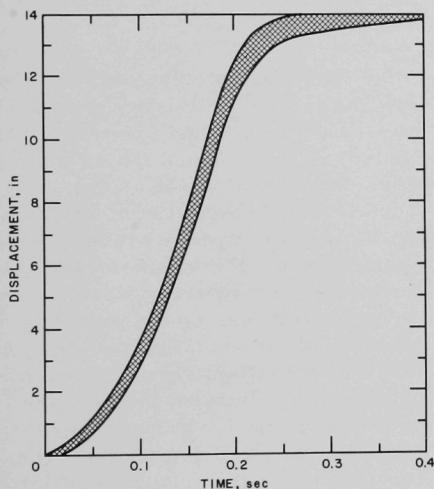


Fig. 19. Rod Displacement vs. Time after Initiation of Scram (Piston Cylinder Pressurized to 35 psig)

filled with static sodium at 600°F , was made to determine the optimum pneumatic pressure required (for both individual and multiple rod scrams) to achieve the specified maximum rod acceleration of 1.4 g to 1.5 g.

b. Scram and Performance Tests Prior to Wet Criticality

Prior to filling the primary tank with sodium, each control rod was driven up and down, then up again and scrammed (without air pressure) to ascertain proper functioning of the mechanism. During these operations, two of the shock-absorber plunger switches required readjustment for positive actuation. In addition, the lifting platform was raised and lowered several times to check limit-switch actuation and to readjust the bottom switch for positive rod gripping. Coincident with these tests, several checks were made of the rod-gripping mechanisms; two mechanisms required slight adjustment.

The final series of scram tests, made with the primary tank

Rod displacement-time curves were plotted on the chart of a light-beam galvanometer, direct-writing, oscillograph. The transmitting equipment consisted of a cable with one end attached to the control drive shaft, and the other end connected to a rotatable, spring-loaded drum. The

shaft of the drum was coupled directly to a single-turn potentiometer. Calibration of the equipment revealed that the oscillograph trace was slightly nonlinear; therefore, corrections were applied to obtain true displacement-time data.

Successive tests at gradually increased air pressures established 30 psig as a satisfactory value for individual rod scrams (see Fig. 20). However, multiple rod scrams at this pressure resulted in a slight drop in acceleration (about 0.05 g); this was offset by increasing the pressure to 33 psig. Subsequent calculations indicated that the maximum accelerations ranged from 1.44 g to 1.50 g, with an average of 1.47 g. The elapsed times for 11 in. of rod travel ranged from 0.201 to 0.228 sec, with an average of 0.209 sec. These travel times are expected to be used in the future as bases for routine checks by operations personnel.

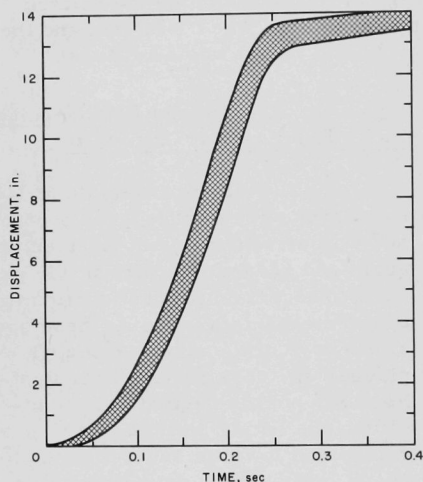


Fig. 20. Rod Displacement vs. Time after Initiation of Scram (Piston Cylinder Pressurized to 30 psig)

the sliding shafts, the design of the drive motors was modified to provide for automatic reversal of the shafts (about 20°) after each actuation. Several minor improvements were also made on the shock-absorber assemblies.

As a result of the foregoing tests and the consequent minor design improvements, the EBR-II control rod drive mechanisms have accumulated more than two years of operation without any malfunction in reactor control.

ACKNOWLEDGMENT

The authors wish to express their appreciation to Mr. M. R. Sims for his efforts in the preparation of this material for publication.

During the course of the dry and the wet criticality experiments, all phases and functions of the control rod drives and lifting platform were demonstrated satisfactorily. Certain changes and/or modifications were made to improve overall system performance. For example, the platform interlock switches were improved by increasing the over-travel capacity of the actuating devices. As mentioned earlier, vertical movement of the lifting platform involves the operation of twelve gripper-jaw-actuating screw-drive shafts. Therefore, to better the angular shaft alignment and thus improve simultaneous engagement and disengagement with

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